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Radioactive Waste

RADIOACTIVITY IN SILT OF THE CLINCH AND TENNESSEE RIVERS

W. D. Cottrell

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RADIOACTIVITY IN SILT OF THE CLINCH AND TENNESSEE RIVERS

W. D. Cottrell

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OAK RIDGE NATIONAL LABORATORY
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A portion of the low level radioactive liquid wastes originating from the Oak Ridge National Laboratory are dispersed into the Tennessee River System by way of White Oak Creek and the Clinch River. Releases are controlled so that the resulting average concentration of radioactivity in the Clinch River complies with permissible levels. The amount of radioactivity leaving White Oak Creek is measured and concentration values in the river are calculated on the basis of the dilution afforded by the river. Radioactive materials are reconcentrated by selective adsorption on clays and by biological action of certain organisms. Such processes, while removing radioactivity directly from the water, tend to concentrate the activity on bottom sediments. By measuring the accumulation of radioactive materials in the downstream bottom sediments, information can be obtained relative to the dispersal of wastes and their subsequent reconcentration in the environment.

Annual surveys have been made of the Clinch and Tennessee Rivers since 1951. The surveys for 1951, 1952, and 1953 were reported by Garner and Kochtitzky.(1) Beginning in 1954 and extending through 1958, the survey was performed by the Area Monitoring Group. It is the work of the Area Monitoring Group that is summarized in the following pages.

II. PURPOSE

Survey objectives were as follows:

1. Evaluate the radioactivity in the bottom sediment in terms of potential present and future hazard to humans.
2. Predict the capacity of the Tennessee River system for storing radioactivity based on the present rate of accumulation.
3. Recommend rates at which radioactive wastes may be dispersed safely.
4. Determine the effect on future industry of an increase in the radioactive content of bottom sediments in the Tennessee River System.

III. INSTRUMENTATION AND PROCEDURE

The boat used in the surveys was a sixteen foot, flat bottomed, outboard hull with a six foot beam, permanently sheltered forward to protect the electronic equipment, and provided with a canvas, aft, to be used if needed. The hull was powered by a 25 HP motor with remote controls and a 5 HP motor for a spare.

A device called a "flounder" (1) (Fig. 1) measured the gamma radiation of the bottom sediments. The "flounder" consisted of twelve battery operated GM tubes (12 inch) connected in parallel. Pulses from the GM tubes were preamplified and recorded on a battery operated decimal scaler, the average count being determined by timing with a stop watch. Samples of bottom sediment for laboratory analysis were obtained with an Eckman Dredge.

Sampling points were located on TVA navigation charts and "cross sections" were taken across the river at these points. A "cross section" consists of readings and sediment samples taken at pre-determined intervals along the traverse from one bank to the other. Fifty foot intervals were used in the Clinch River, but an average of ten readings and samples were taken per traverse in the Tennessee River and in the reservoirs.

Cross sections were taken every two miles in the Clinch and approximately every 10 miles in the Tennessee River and in the reservoirs. Downstream from the dams the action of the water has scoured the river bed of sediment; therefore, no readings were taken for some distance.

A 3/16" cable laid across the Clinch River by means of a block and

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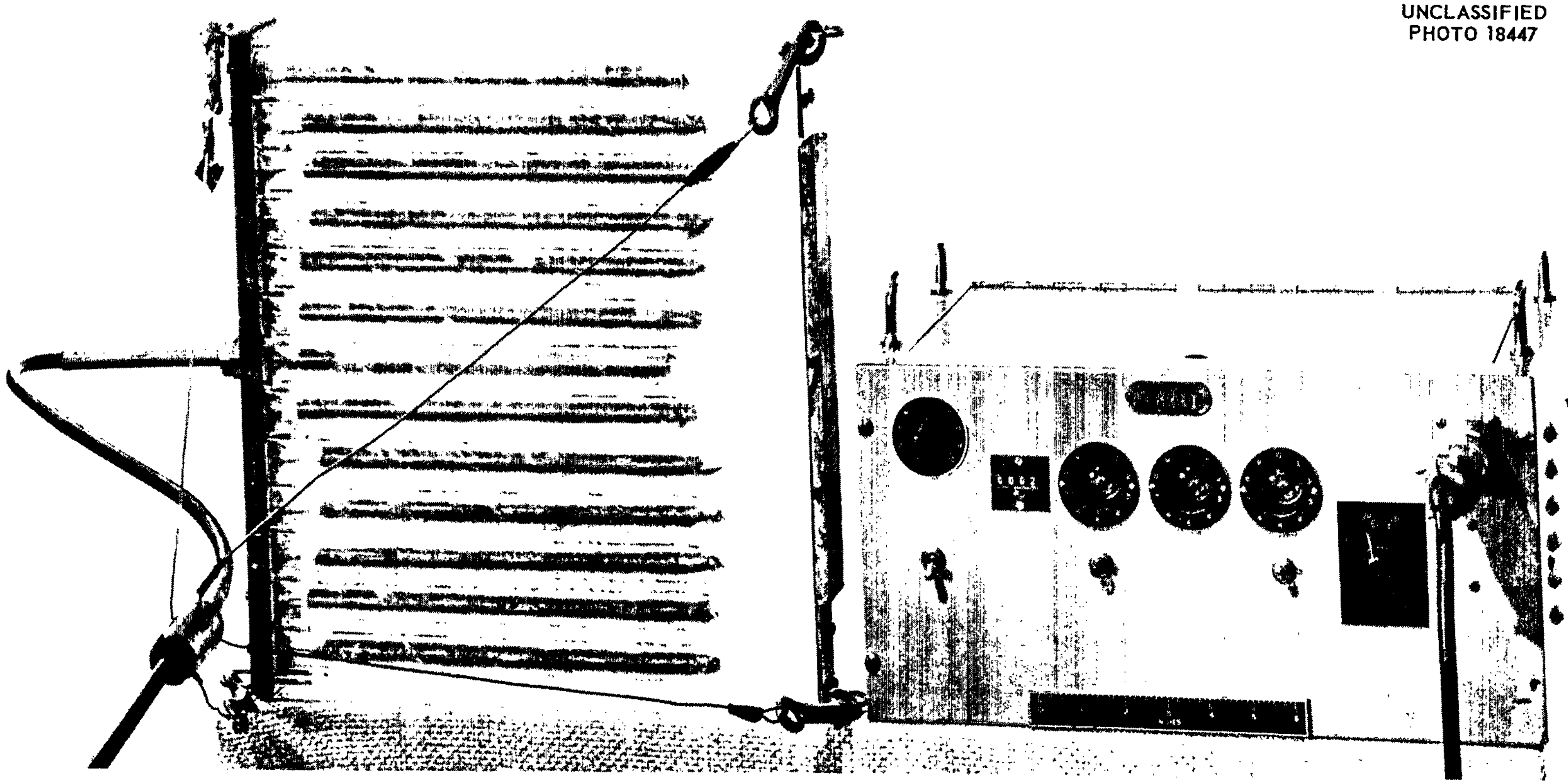

Fig. 1. Flounder and Decimal Scaler Used in River Survey.

tackle was used to anchor the boat. Tags at 50 foot intervals along the cable located the sampling points along the traverse. Fig. 2 shows the boat clamped to the cable and radiation detection instruments being lowered to the bottom. The man in the bow is using an Eckman Dredge to collect silt samples.

In the Tennessee River the location along the traverse was determined as follows: First, a complete traverse was made and the time for the crossing was noted. The time thus obtained was divided by one more than the number of readings to be taken. Second, markers were thrown out at appropriate intervals as the boat moved across the river again with identical motor control settings and load distribution. Sealed one quart tin cans with a piece of lead attached by a fishing cord served as markers. Silt range data were furnished by the TVA and, where possible, cross sections were taken along these ranges. The bottom contours shown by the silt range data were used to check or to correct the locations determined by the above method.

After the boat was secured by three anchors, two abow, and one astern, the flounder was lowered to the bottom of the river. The depth was recorded and the count taken for five minutes or until 3000 counts had been accumulated. While the count was in progress, a sample of bottom sediment was obtained with the Eckman Dredge, the sample being collected on the opposite side of the boat from the flounder to prevent the sediment, stirred up by the dredge, from influencing the count of the flounder.

Background data were taken in Norris and Fort Loudoun reservoirs.

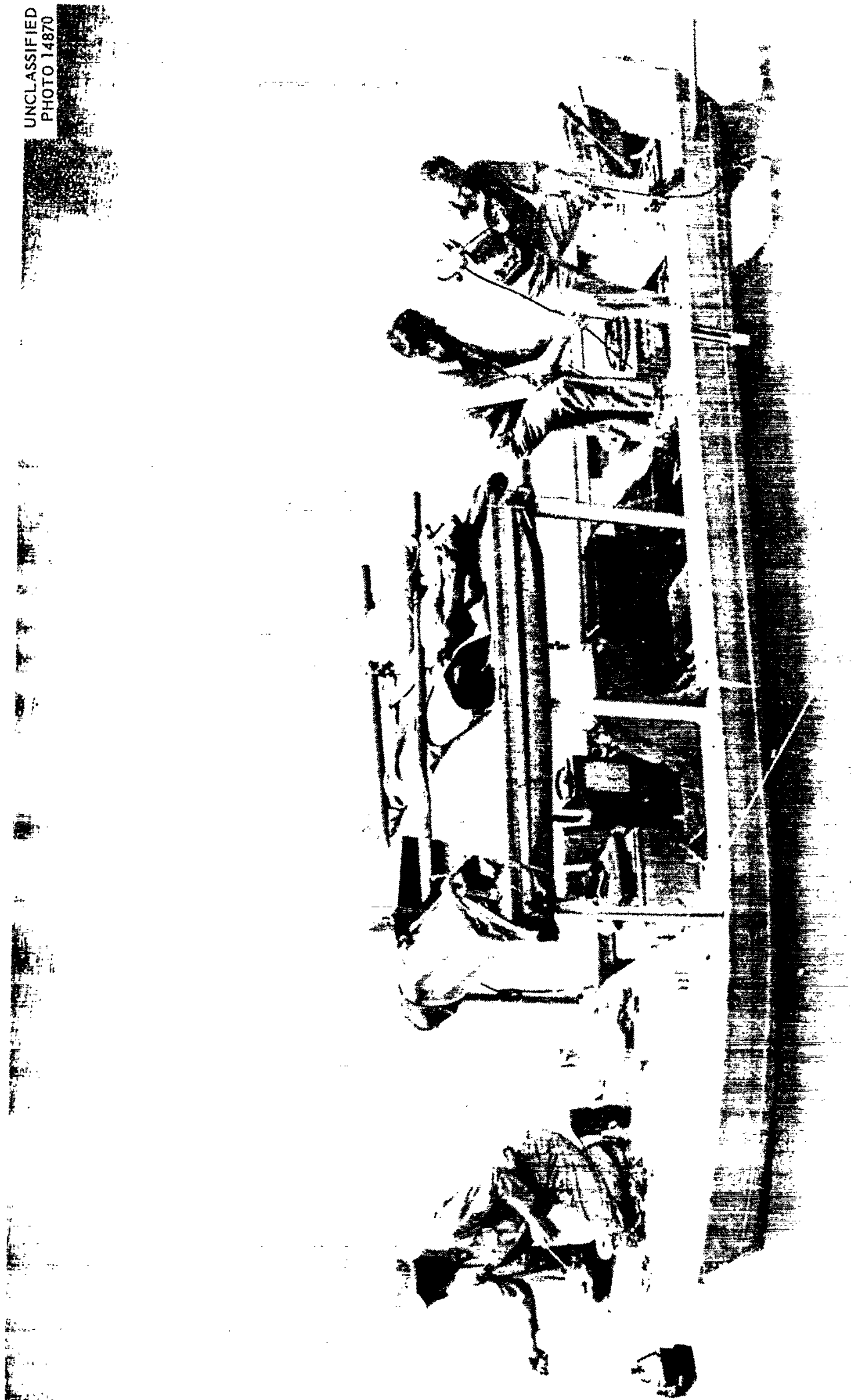

Fig. 2. Boat and Equipment Used in River Survey.

Readings were taken in Norris from zero depth to a depth greater than 100 feet. The readings in Fort Loudoun were confined mostly to bottom readings to provide "mud background" data for comparison with data obtained downstream from ORNL. A curve of counts per second versus depth was plotted from the Norris data and this was used to correct the downstream readings for cosmic background.

IV. PRESENTATION OF DATA

The wastes from ORNL enter the Clinch River via White Oak Creek at Clinch River mile 20.8. At full pool, Watts Bar reservoir backwater extends upstream to Clinch River mile 28, but at minimum pool it extends only to the mouth of White Oak Creek (CRM 20.8).

Readings were taken in the Clinch River from mile 27.5, 6.7 miles above the mouth of White Oak Creek to the confluence of the Clinch and Tennessee Rivers, TRM 567.6 and in the Tennessee River from TRM 570.8 to 475.1. The 1957 and 1958 surveys extended downstream as far as TRM 354.4.

Fig. 3 shows that section of the Tennessee River System over which the surveys were made. The sampling locations and origin of the wastes are shown with the river mile location of each indicated.

The "mud background" readings taken in Fort Loudoun reservoir ranged from 7 c/s in 1954 to 13 c/s in 1958. The average over the four year period was approximately 10 c/s.

The gamma measurements made on the bottom sediment were corrected for "cosmic background" and averaged for each cross-section. Plots of the average count versus river mile for the Clinch and Tennessee Rivers are given in Figs. 4 and 5.

All gamma counts (c/s) taken in the Clinch River were totalized and divided by the numbers of readings to obtain an average gamma count for that particular year. The data for the Tennessee River were treated likewise. These data together with the curies discharged to the Clinch River for the period 1951[1] to 1958 are given in Fig. 6.

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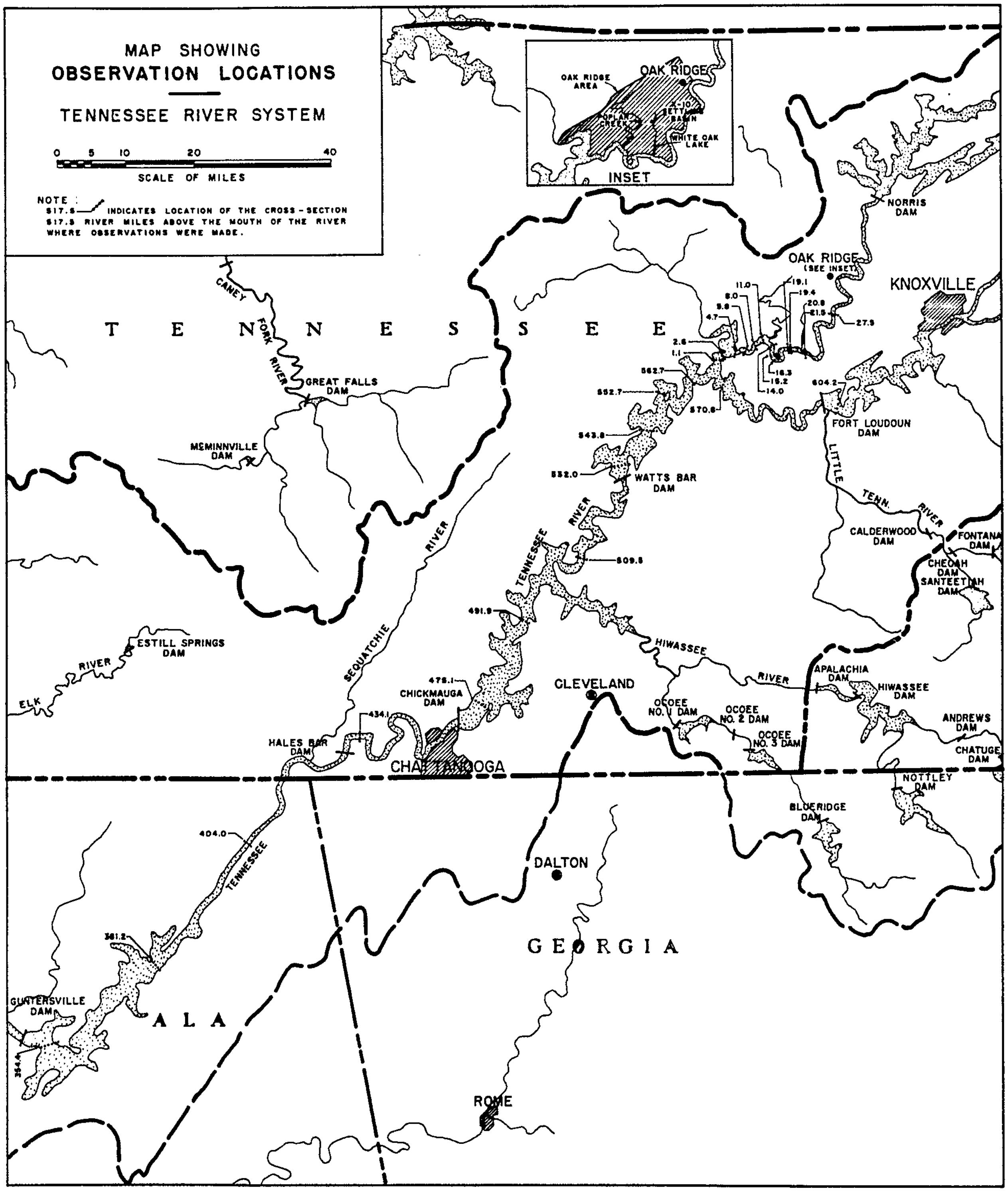

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Fig. 3.

A composite silt sample was prepared for each cross section. Aliquots of the composite sample were counted for gross beta activity and analyzed radiochemically for long lived fission products. The gross beta activity, reported in terms of Tl^{204}*, is shown versus river mile in Figs. 7 and 8.

The results of the radiochemical assay of the river silt are given in Tables I through VI. These data, listed according to location where samples were taken, cover the period 1954-58 and give the amount of each radionuclide found in units of 10^{-6} μc/gram of dried silt. The radionuclide content of the silt was averaged for both the Clinch and Tennessee Rivers and is presented graphically in Fig. 9. The total curies of each radionuclide discharged to the Clinch River during the corresponding year is given in the upper half of Fig. 9.

A comparison is made in Table VII of the gross beta activity found in the silt and the gamma count taken with the flounder at the surface of the silt.

Bottom contours and activity profiles were plotted for each cross section for the 1954 survey and are given in Figs. 10 through 14.

* The counting efficiency of the counters was determined using Tl^{204} as a standard. The values reported as μc of gross beta activity would be true only if all the activity were Tl^{204}.

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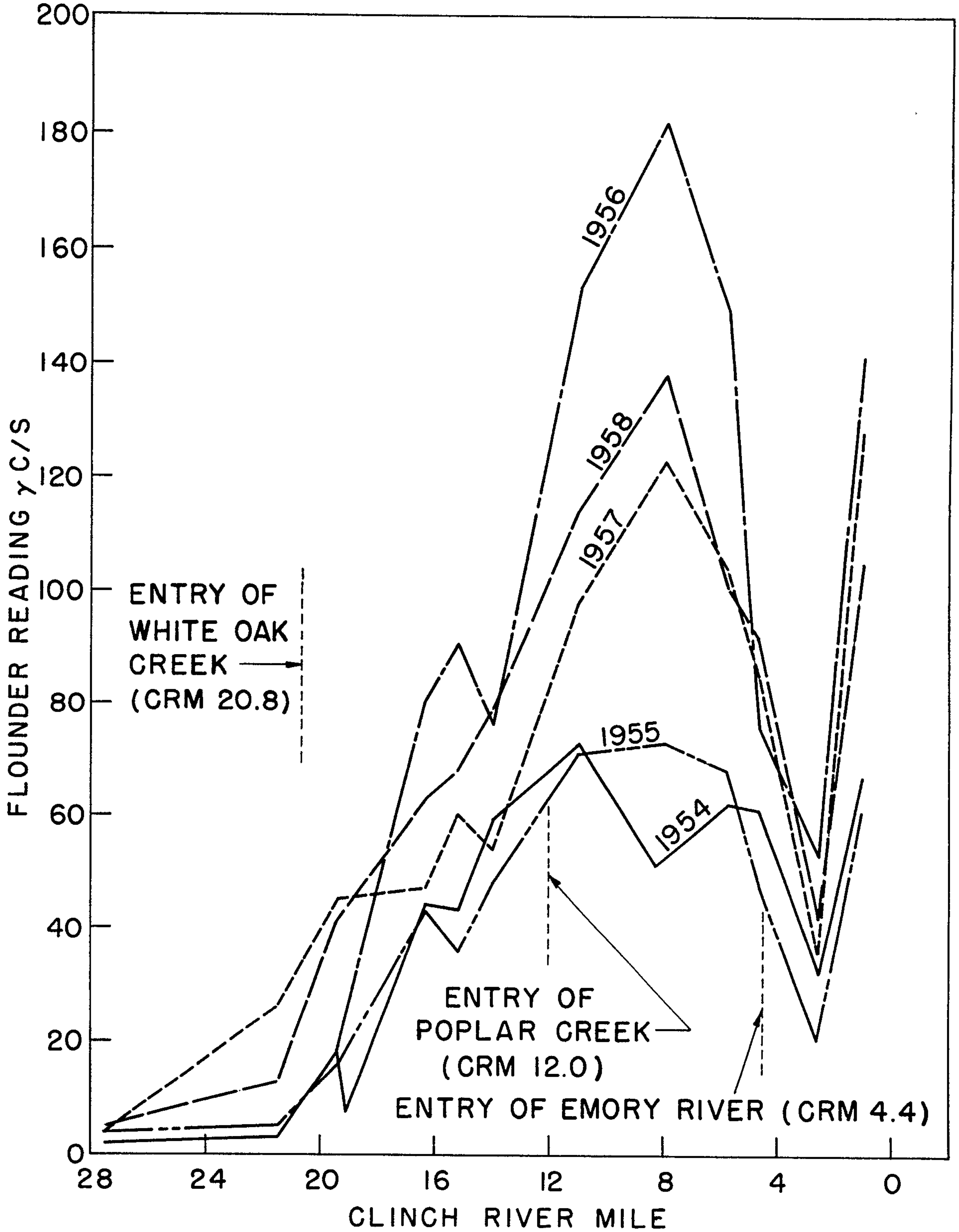

Fig. 4. Gamma Count at Surface of Clinch River Sediment.

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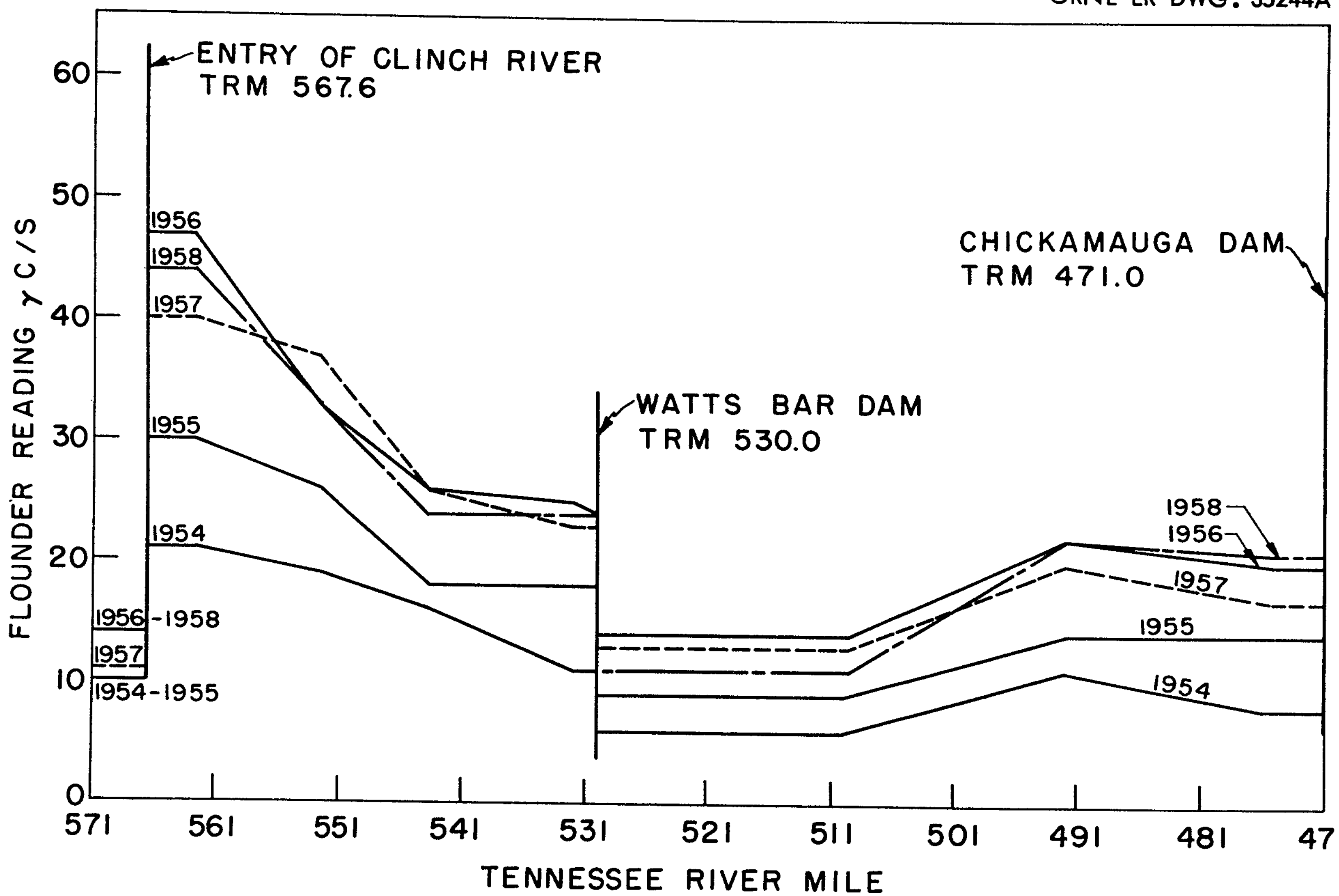

Fig. 5. Gamma Count at Surface of Tennessee River Sediment.

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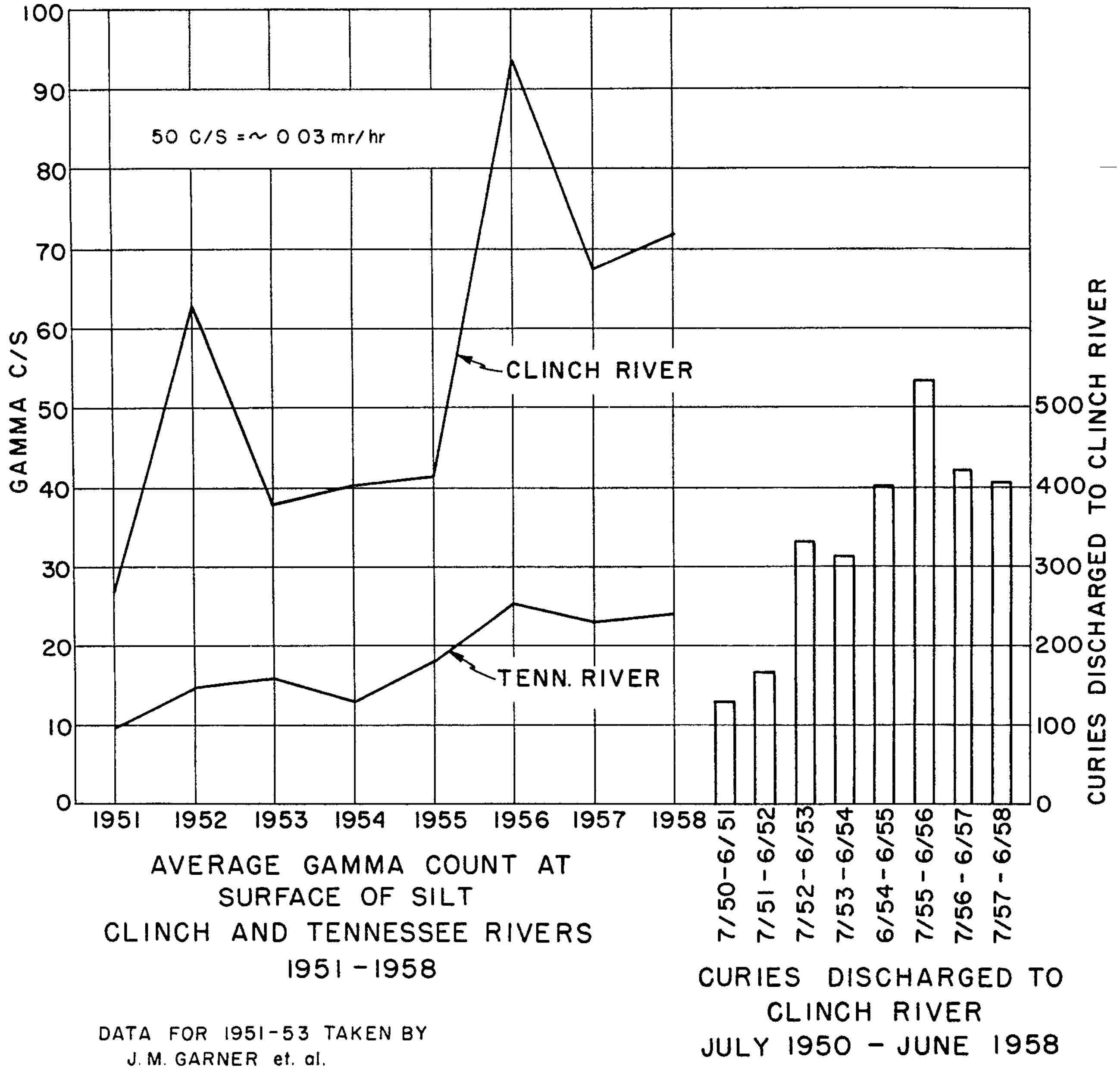

Fig. 6.

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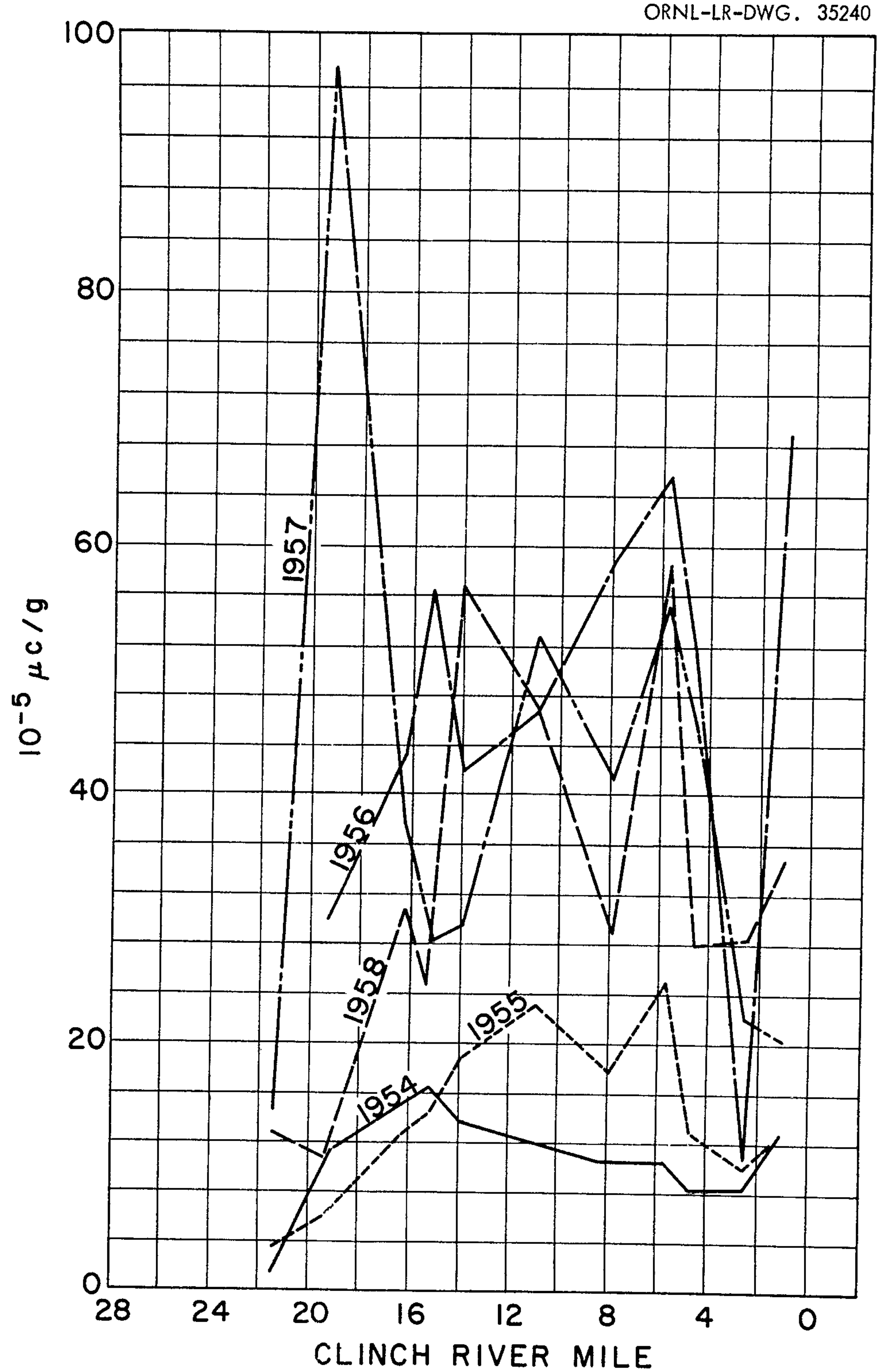

Fig. 7. Gross Beta Activity of Clinch River Silt.

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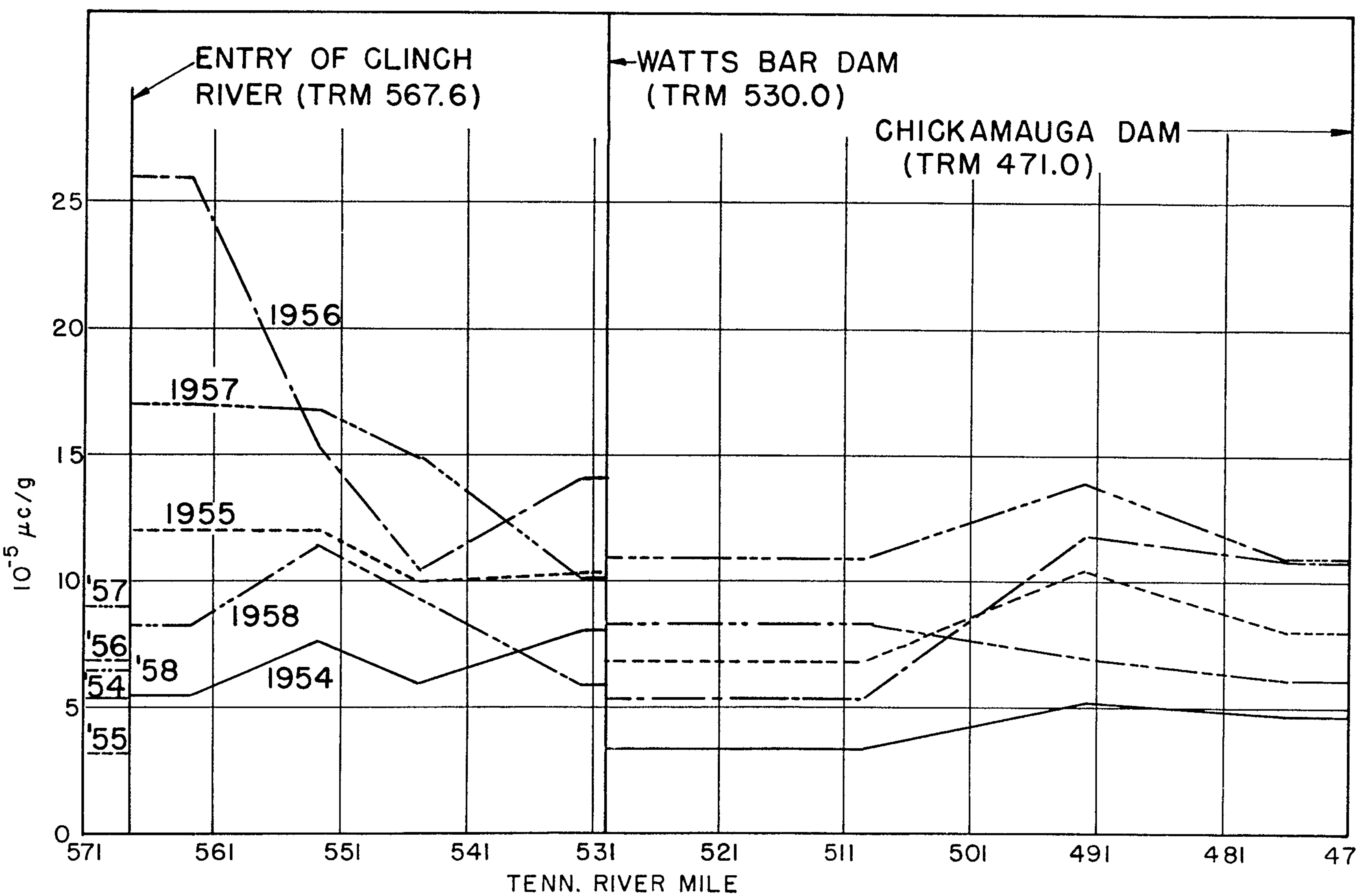

Fig. 8. Gross Beta Activity of Tennessee River Silt.

TABLE I

Cesium in River Silt 1954-58*
Activity in Units of 10^{-6} μc/g of Dried Mud

Sample Location	Cesium (as Cs-Ba137) 54	55	56	57	58
Tenn. R. M. 604.1 Ft. Loudoun Lake**	2	2	5	-	2
Clinch R. M. 21.5	3	5	-	5	4
19.1	12	7	116	528	44
16.3	27	22	208	177	223
15.2	22	34	268	119	146
14.0	24	29	115	184	298
11.0	22	34	144	251	236
8.3	22	38	244	178	170
5.7	24	29	266	299	223
4.7	22	-	-	236	151
2.6	15	-	-	173	92
1.1	24	25	257	192	167
Average	19.7	24.8	202.2	213.1	159.3
Tenn. R. M. 570.8	3	-	-	5	2
562.7	10	7	73	55	51
552.7	12	-	-	57	36
534.8	5	-	-	47	22
532.0	10	11	32	39	21
509.5	3	-	-	20	10
491.9	5	-	20	20	16
475.1	5	2	14	16	13
Average	6.6	6.7	35	32.3	21.4
Tenn. R. M. 434.1				13	9
381.2				7	7
354.5				7	4

* All samples were taken during summer. No data is available on month to month changes.

** Background

TABLE II

Strontium in River Silt 1954-58*
Activity in Units of 10^{-6} μc/g of Dried Mud

Sample Location		Strontium (as Sr^{90}) 54	55	56	57	58
Tenn. R.M. 604.1 Ft. Loudoun Lake**		2	1.4	1.3	-	1.1
Clinch R.M.	21.5	1	-	-	1	1
	19.1	5	-	4	3	2
	16.3	5	4	7	5	6
	15.2	5	-	9	5	6
	14.0	5	4	4	3	11
	11.0	5	4	6	5	13
	8.3	4	4	6	5	6
	5.7	4	4	6	7	1
	4.7	4	-	-	5	8
	2.6	3	-	-	3	5
	1.1	4	3	6	3	5
	Average	3.6	3.8	6	4.1	5.9
Tenn. R.M.	570.8	2	-	-	0.9	1.0
	562.7	2	0.3	3	0.8	2.0
	552.7	2	-	-	0.5	1.5
	543.8	2	-	-	0.9	1.7
	532.0	4	0.4	3	0.6	1.7
	509.5	3	-	-	1	1.6
	491.9	2	-	2	0.6	.1
	475.1	2	0.3	2	1.3	1.3
	Average	2.4	0.3	2.5	0.76	1.41
Tenn. R.M.	434.1				1.4	1.2
	381.2				0.8	1.9
	354.5				0.7	1.5

* All samples were taken during summer. No data is available on month to month changes.

** Background

TABLE III

Cerium in River Silt 1954-58*
Activity in Units of 10^{-6} $\mu c/g$ of Dried Mud

Sample Location		Cerium (as $Ce-Pr^{144}$)				
		54	55	56	57	58
Tenn. R.M. 604.1 Ft. Loudoun Lake**		1	1.7	3	-	4.7
Clinch R.M.	21.5	2	4	-	5	12
	19.1	5	6	24	33	7
	16.3	8	21	37	12	20
	15.2	7	32	56	9	22
	14.0	8	22	20	7	43
	11.0	8	31	41	10	40
	8.3	5	32	48	10	16
	5.7	8	40	56	12	24
	4.9	7	-	-	13	21
	2.6	4	-	-	9	17
	1.1	5	30	44	13	22
Average		6.1	24.2	40.8	12.1	22.2
Tenn. R.M.	570.8	1	-	-	1.3	5.7
	562.7	2	13	15	5.5	8.0
	552.7	2	-	-	4.3	9.6
	543.8	1	-	-	3.0	7.2
	532.0	2	15	8	2.6	4.9
	509.5	1	-	-	1.9	6.2
	491.9	2	-	6	1.8	4.6
	475.1	2	4	4	1.6	6.2
Average		1.6	10.7	8.3	2.7	6.6
Tenn. R.M.	434.1				3.4	7.2
	381.2				3.4	5.4
	354.5				1.6	4.7

* All samples were taken during summer. No data is available on month to month changes.

** Background

TABLE IV

Tri-Valent Rare Earths in River Silt 1954-58*
Activity in Units of 10^{-6} $\mu c/g$ of Dried Mud

Sample Location		Tri-valent R.E. + Yttrium (as Y^{90})				
		54	55	56	57	58
Tenn. R.M. 604.1 Ft. Loudoun Lake**		2	1.7	3	-	4.8
Clinch R.M.	21.5	1	3	-	2	3
	19.1	2	3	7	10	6
	16.3	4	5	11	5	13
	15.2	4	7	15	4	17
	14.0	4	8	7	4	21
	11.0	6	16	19	8	18
	8.3	4	24	19	6	14
	5.7	8	12	18	7	15
	4.9	5	-	-	6	13
	2.6	5	-	-	5	10
	1.1	4	9	15	5	12
	Average	4.4	9.7	13.8	5.6	12.7
Tenn. R.M.	570.8	1	-	-	1.1	5.1
	562.7	3	6	6	1.9	5.5
	552.7	1	-	-	2.7	6.1
	543.8	2	-	-	1.3	5.5
	532.0	4	7	4	1.5	5.5
	509.5	3	-	-	1.7	6.1
	491.9	2	-	3	1.3	5.3
	475.1	2	6	1.8	1.0	6.4
	Average	2.3	6.2	3.7	1.6	5.7
Tenn. R.M.	434.1				1.8	8.1
	381.2				1.3	2.6
	354.5				1.4	4.7

* All samples were taken during summer. No data is available on month to month changes.

** Background

TABLE V

Ruthenium in River Silt 1954-58*
Activity in Units of 10^{-6} µc/g of Dried Mud

Sample Location		Ruthenium (as $Ru-Rh^{106}$) 54	55	56	57	58
Tenn. R.M. 604.1 Ft Loudoun Lake**		1	0.5	3	-	4.6
Clinch R.M.	21.5	1	-	-	3	6
	19.1	8	-	5	14	3
	16.3	5	4	8	6	7
	15.2	5	-	11	3	6
	14.0	6	4	6	4	16
	11.0	2	5	7	6	12
	8.3	5	4	10	5	7
	5.7	5	8	8	6	11
	4.9	5	-	-	5	10
	2.6	5	-	-	4	6
	1.1	3	4	10	6	10
Average		4.5	4.8	8.1	5.6	8.6
Tenn. R.M.	570.8	3	-	-	1.3	2.6
	562.7	2	3	4	3.1	4.1
	552.7	1	-	-	3.4	5.4
	543.8	2	-	-	3.1	3.1
	532.0	1	4	3	2.0	2.0
	509.5	1	-	-	2.3	3.4
	491.9	1	-	2	1.8	3.7
	475.1	1	1	3	1.5	3.5
Average		1.5	2.7	3.0	2.3	3.5
Tenn. R.M.	434.1				2.9	3.5
	381.2				0.9	2.5
	354.5				1.7	2.3

* All samples were taken during the summer. No data is available on month to month changes.

** Background

TABLE VI

Cobalt in River Silt 1954-58*
Activity in Units of 10^{-6} μc/g of Dried Mud

Sample Location		Cobalt (as Co^{60}) 54	55	56	57	58
Tenn. R.M. 604.1 Ft. Loudoun Lake**		4	0.0	1.0	-	0.6
Clinch R.M.	21.5	3	2	-	-	3
	19.1	11	-	26	30	4
	16.3	19	18	39	15	21
	15.2	19	-	59	14	9
	14.0	19	23	29	17	16
	11.0	19	25	37	15	15
	8.3	23	29	50	15	17
	5.7	31	26	52	18	17
	4.9	27	-	-	15	14
	2.6	19	-	-	13	9
	1.1	23	21	46	16	13
	Average	19.4	20.6	42.2	15.2	12.4
Tenn. R.M.	570.8	4	-	-	1	0.8
	562.7	8	7	11	6	5.7
	552.7	6	-	-	6	6.1
	543.8	7	-	-	5	3.6
	532.0	7	13	7	3	2.9
	509.5	4	-	-	2	2.1
	491.9	5	-	4	3	3.1
	475.1	5	4	6	3	1.7
	Average	5.8	8.0	7.0	3.6	3.3
Tenn. R.M.	434.1				2.0	1.7
	381.2				2.0	1.7
	354.5				0.3	2.5

* All samples were taken during summer. No data is available on month to month changes.

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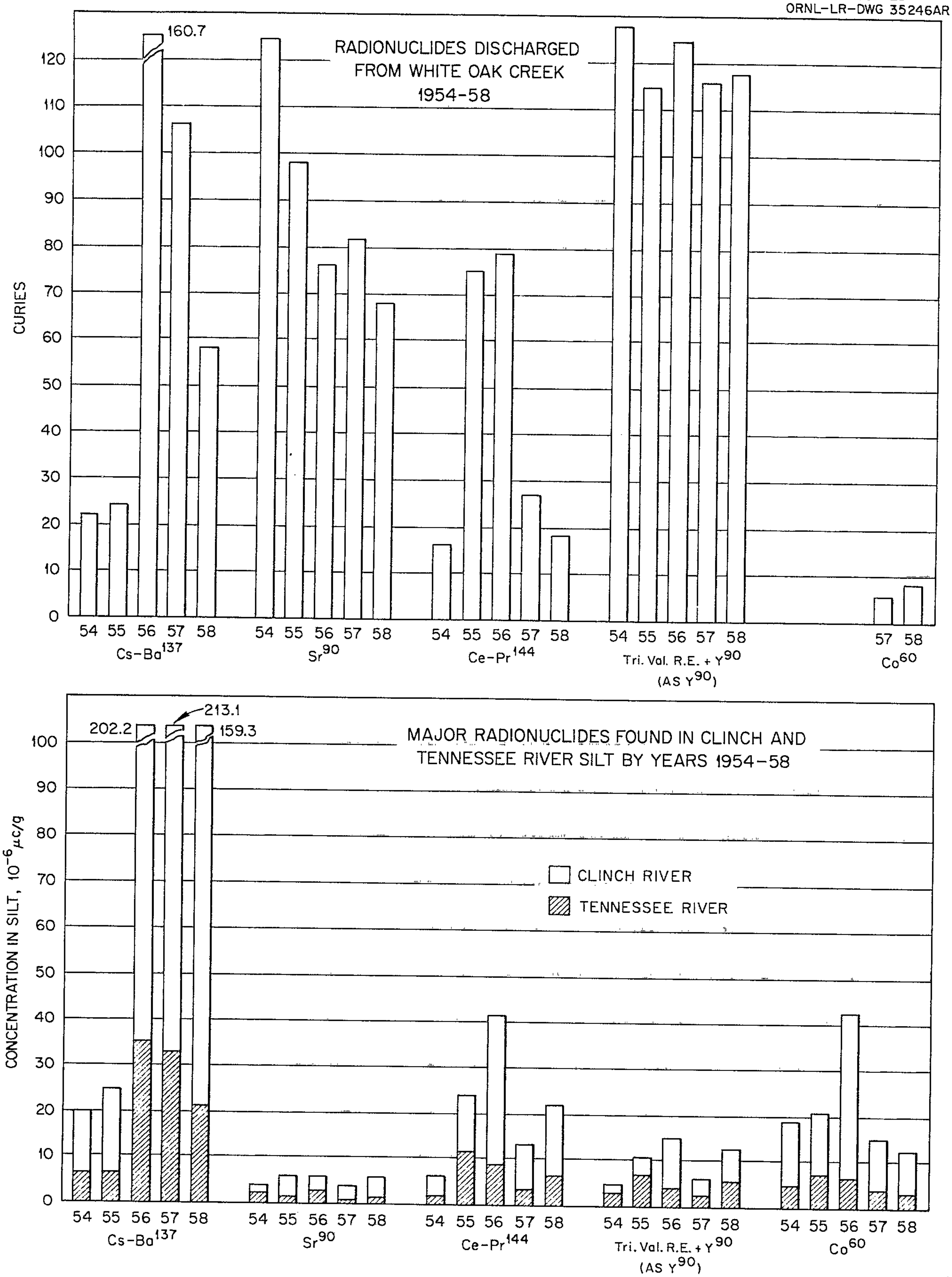

FIG. 9

TABLE VII

Gross Beta Count vs. Gamma Count

	1954			1955			1956			1957			1958		
	Gross β 10^{-5} μc/g	Gamma c/s	Ratio β-γ	Gross β 10^{-5} μc/g	Gamma c/s	Ratio β-γ	Gross β 10^{-5} μc/g	Gamma c/s	Ratio β-γ	Gross β 10^{-5} μc/g	Gamma c/s	Ratio β-γ	Gross β 10^{-5} μc/g	Gamma c/s	Ratio β-γ
Clinch River	11	40	.275	14	42	.333	43	94	.457	40	67	.597	33	72	.458
Tennessee River	6	12	.50	9	17	.53	13	25	.52	13	23	.565	8	24	.333

V. CALIBRATION OF INSTRUMENTS

The flounder used in the surveys consisted of twelve glass wall, organic filled GM tubes connected in parallel. It was calibrated in terms of mr/hr by the use of a water solution of 0.1 mg of radium sealed in a glass ampule. This calibration was made to determine the sensitivity of the instrument and to permit direct comparison of the data taken from year to year. The radium calibration data for the years 1954-58 are given in Figure 15.

A modified version of the flounder was constructed in 1957 using stainless steel wall, halogen filled GM tubes. This flounder proved to be more sensitive than the old flounder, both to radium and to the activity in the river silt. During the 1957 survey, duplicate readings were taken using the old and new flounders. These readings were compared point by point and the comparison ratios averaged for both the Clinch and Tennessee Rivers. The readings taken with the modified flounder were consistently higher than those taken with the old flounder, the ratio of modified to old being 1.36 in the Clinch River and 1.24 in the Tennessee River.

The data presented in this report for the period 1954-57 were taken with the old flounder. The 1958 data were taken with the modified flounder and have been corrected for the difference in sensitivity between the two instruments in order that comparisons of the year to year data could be made.

As an aid in relating the gamma count as measured by the flounder to the radioactive content of the bottom sediment, mud from White Oak

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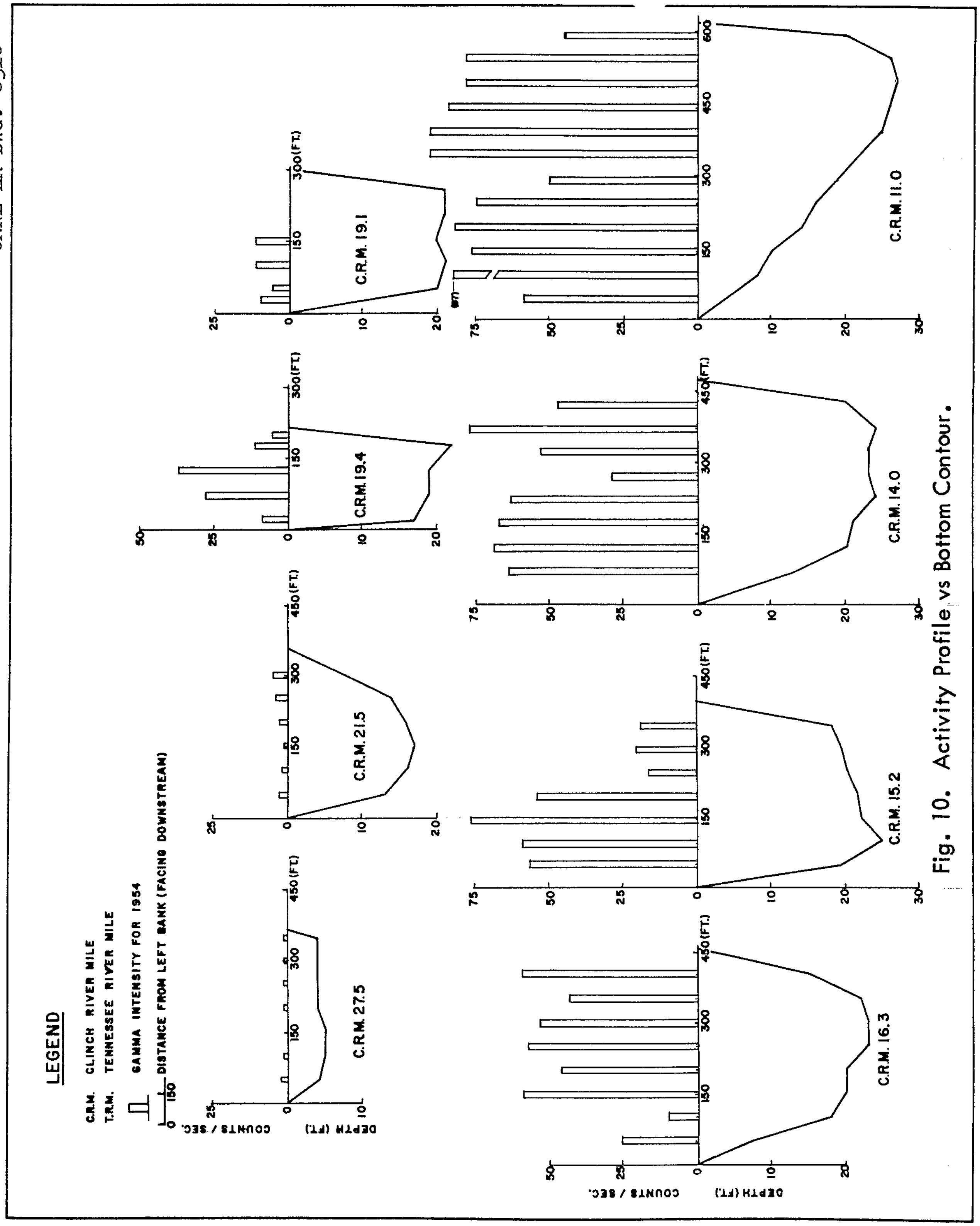

Fig. 10. Activity Profile vs Bottom Contour.

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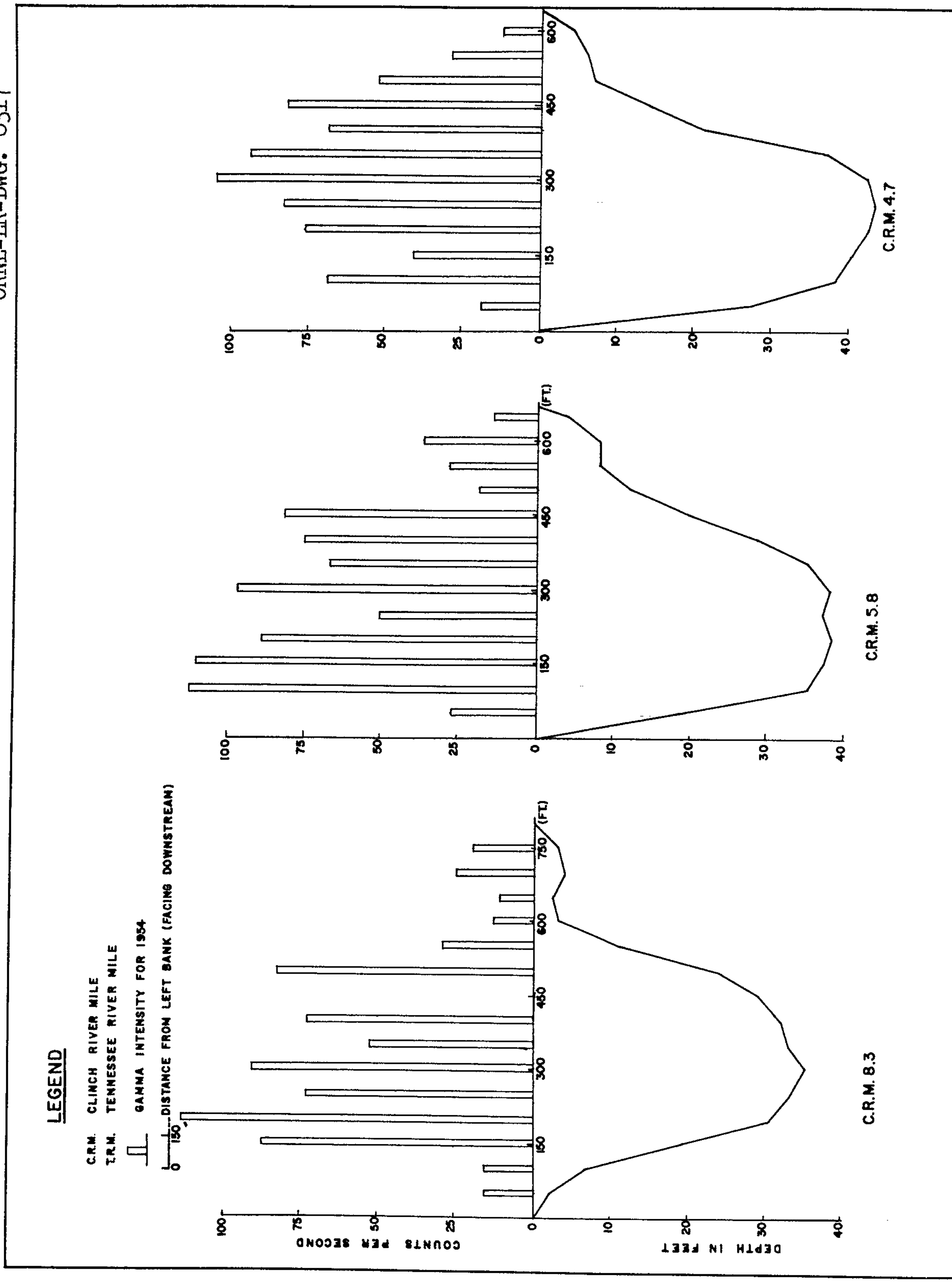

Fig. 11. Activity Profile vs Bottom Contour.

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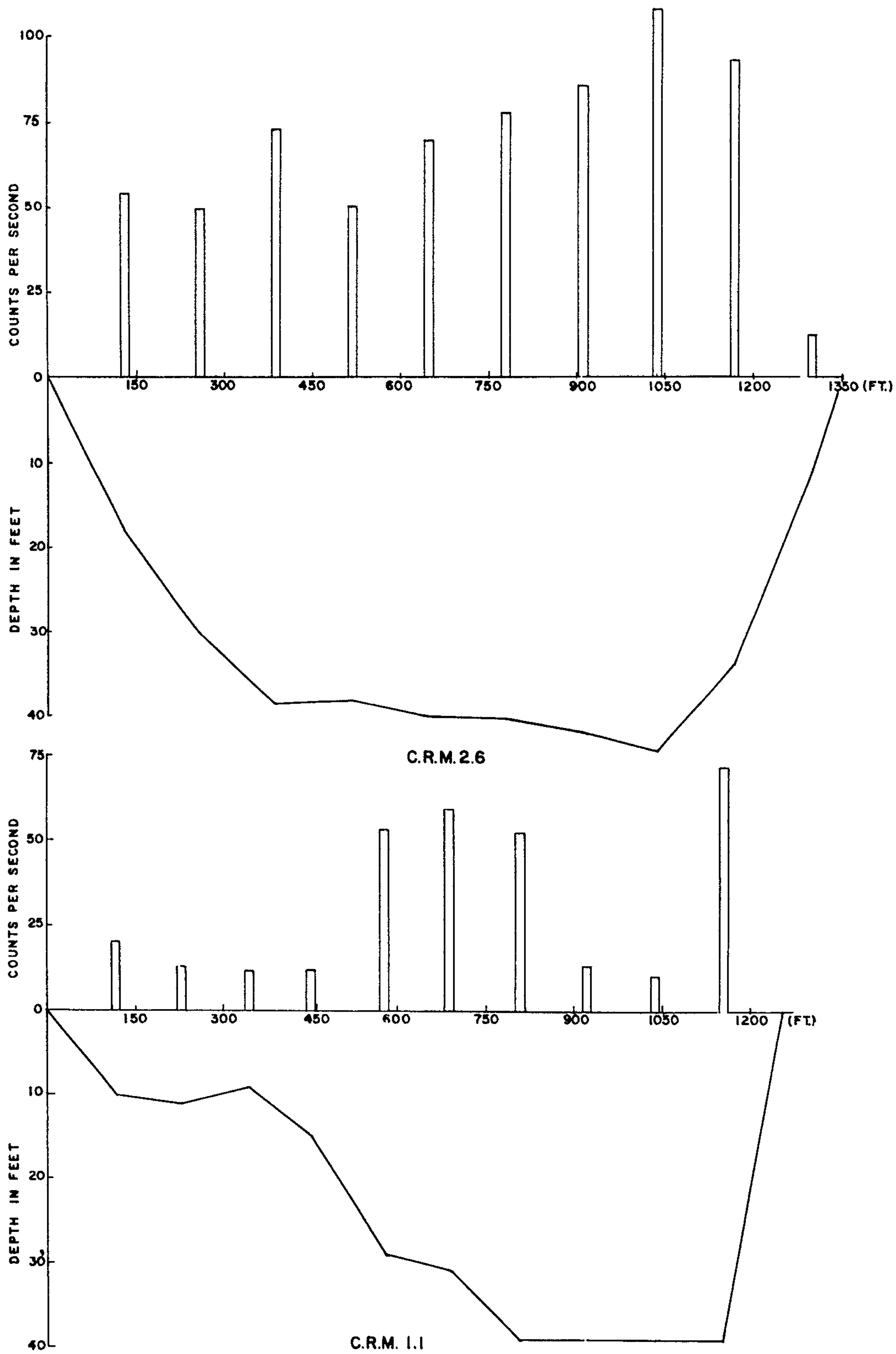

Fig. 12. Activity Profile vs Bottom Contour.

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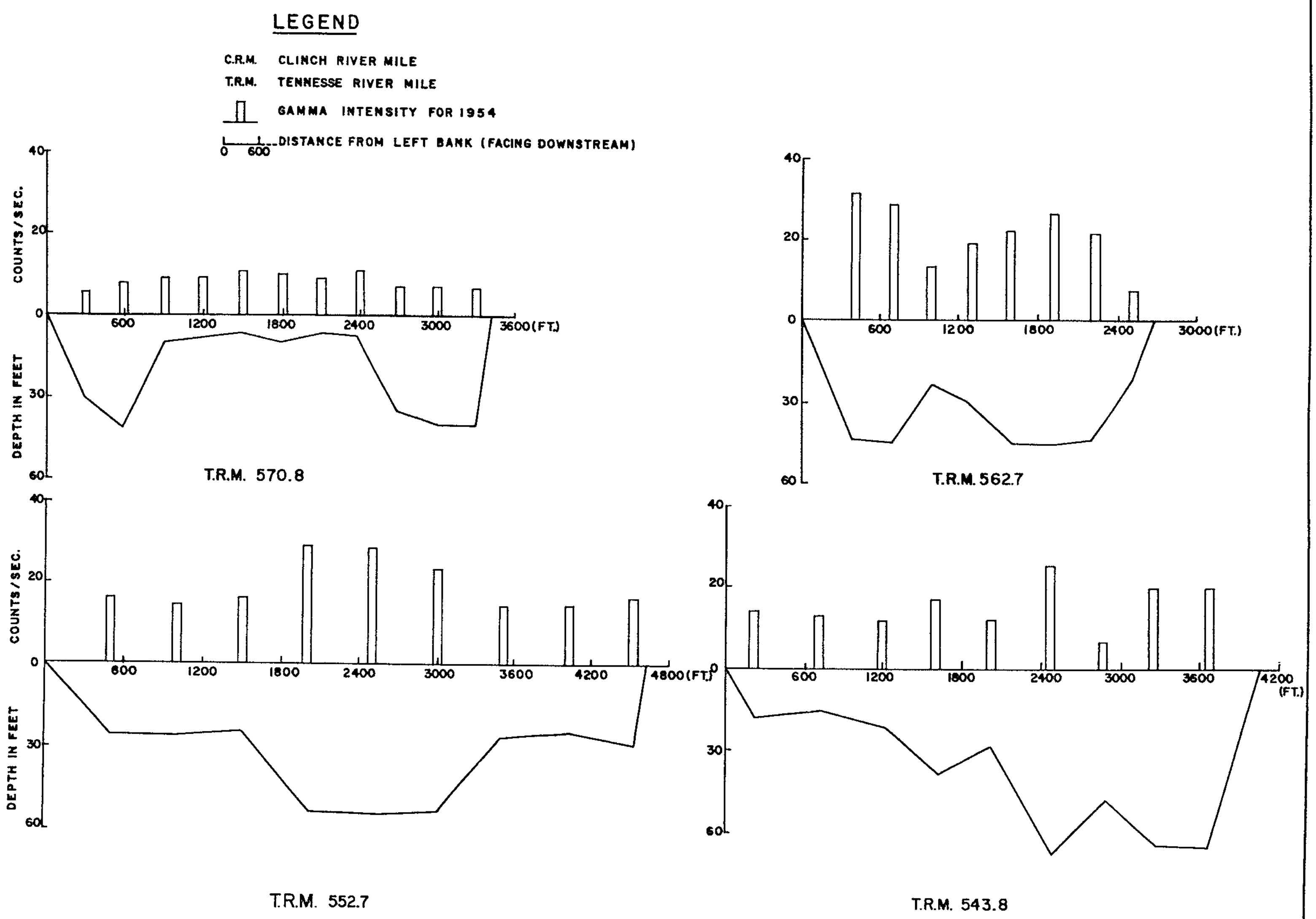

Fig. 13. Activity Profile vs Bottom Contour.

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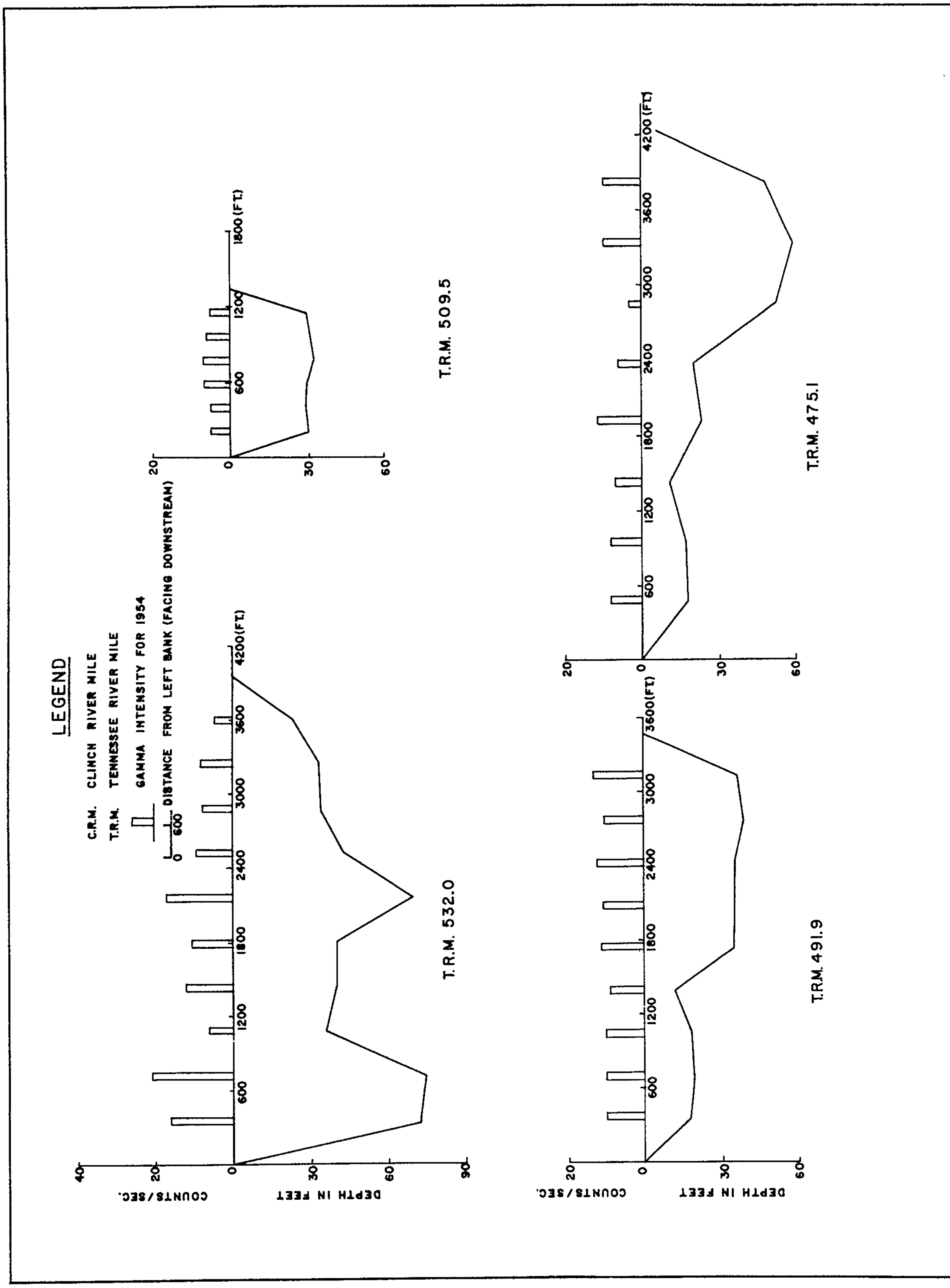

Fig. 14. Activity Profile vs Bottom Contour.

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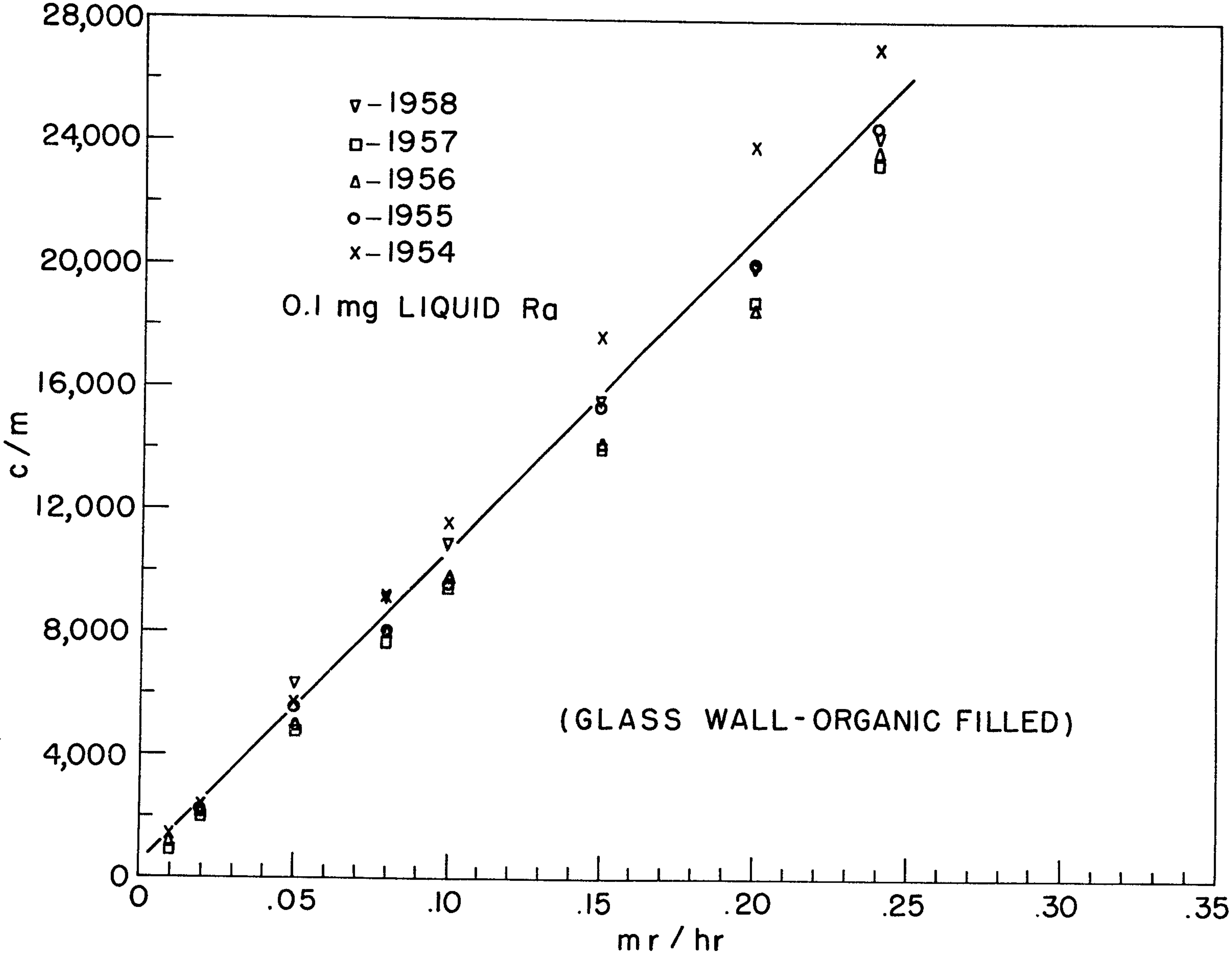

Fig. 15. Calibration of Flounder.

Lake, diluted with uncontaminated mud from Douglas Reservoir was used to calibrate the flounder in terms of μc/g of radioactive silt. A gross beta count, a gamma count, and a radiochemical assay were run on White Oak Lake mud before it was diluted with the uncontaminated mud. Done in this manner, the level of activity was high enough to give low statistical errors in counting and to give reliable radiochemical analyses.

Calibration curves were run for two different thicknesses of mud, four inches and 10-1/2 inches. Figure 16 is a plot of gamma counts per second versus beta activity in μc/g of dry mud. A comparison of the two calibration curves indicates there is considerable absorption of the gamma radiation by these thicknesses of mud.

Since the observed gamma count was due to a mixture of radioactive substances having different gamma energies, and since the composition of the mixture was not very accurately known, the absorption by the mud could only be approximated.

An approximation for the absorption was made by R. H. Ritchie using the expression as follows:

$$I = \frac{\sigma}{2\mu}\left[2 - E_2(\mu t) - e^{-\mu t}\right] \qquad (1)$$

Where μ = absorption coefficient of the mud for the gamma involved

t = thickness of active mud deposit

I = gamma counts observed

σ = specific activity of mud, and

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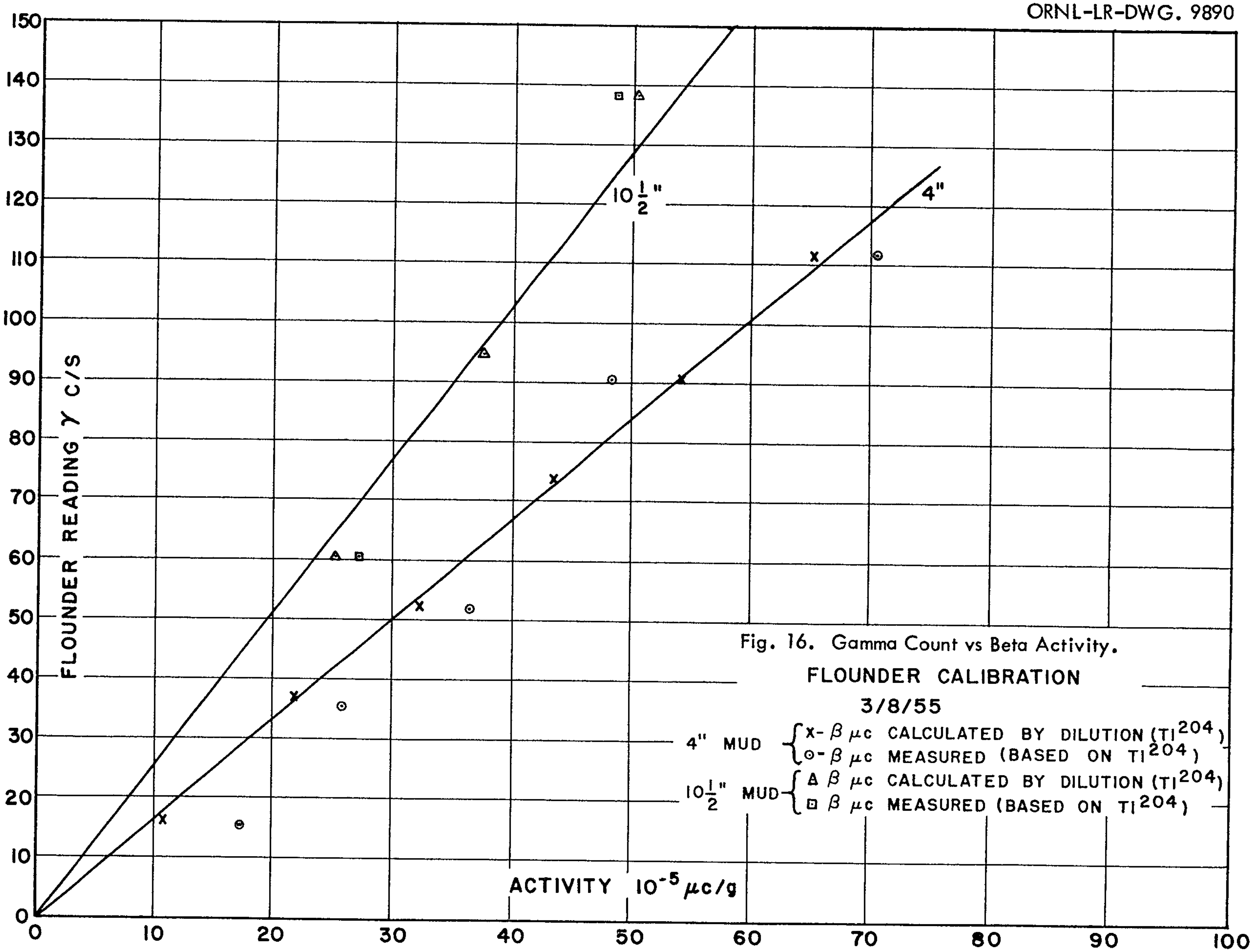

Fig. 16. Gamma Count vs Beta Activity.

E_2 is given by

$$E_2(x) = \int_1^\infty \frac{e^{-yx}}{y^2} \, dy \tag{2}$$

A plot (Figure 17) was made of μt against I_t/I_∞, I_t being the gamma flux at thickness t and I_∞ being the flux from an infinitely thick layer of mud.

The quantity μ was evaluated emperically from this equation and from the data observed on the 4" and 10.5" layers of mud. The procedure was to calculate ratios $I\,(\mu t_2)/\,I\,(\mu t_1)$ from the graph using μt_2 and μt_1 values which were in the same ratio as the experimental thicknesses, $\mu t_2 = \frac{10.5}{4} \mu t_1$. The value of μt_1 was found which gave the same $I(\mu t_2)/I\,(\mu t_1)$ value as that observed experimentally. A value of .0506 cm^{-1} was found for μ.

Using values from this curve and the specific activity and flounder readings from the spiked mud, curves were prepared showing gamma activity in c/s versus specific activity in $\mu c/g$ and gamma activity versus $\mu c/ft^2$. These curves are shown in Figure 18.

If the depth of radioactive silt on the bottom of the streams and reservoirs were known, the total amount of radioactivity per unit area of bottom surface could be estimated. However, with our present equipment, it is impracticable to obtain this information with acceptable accuracy.

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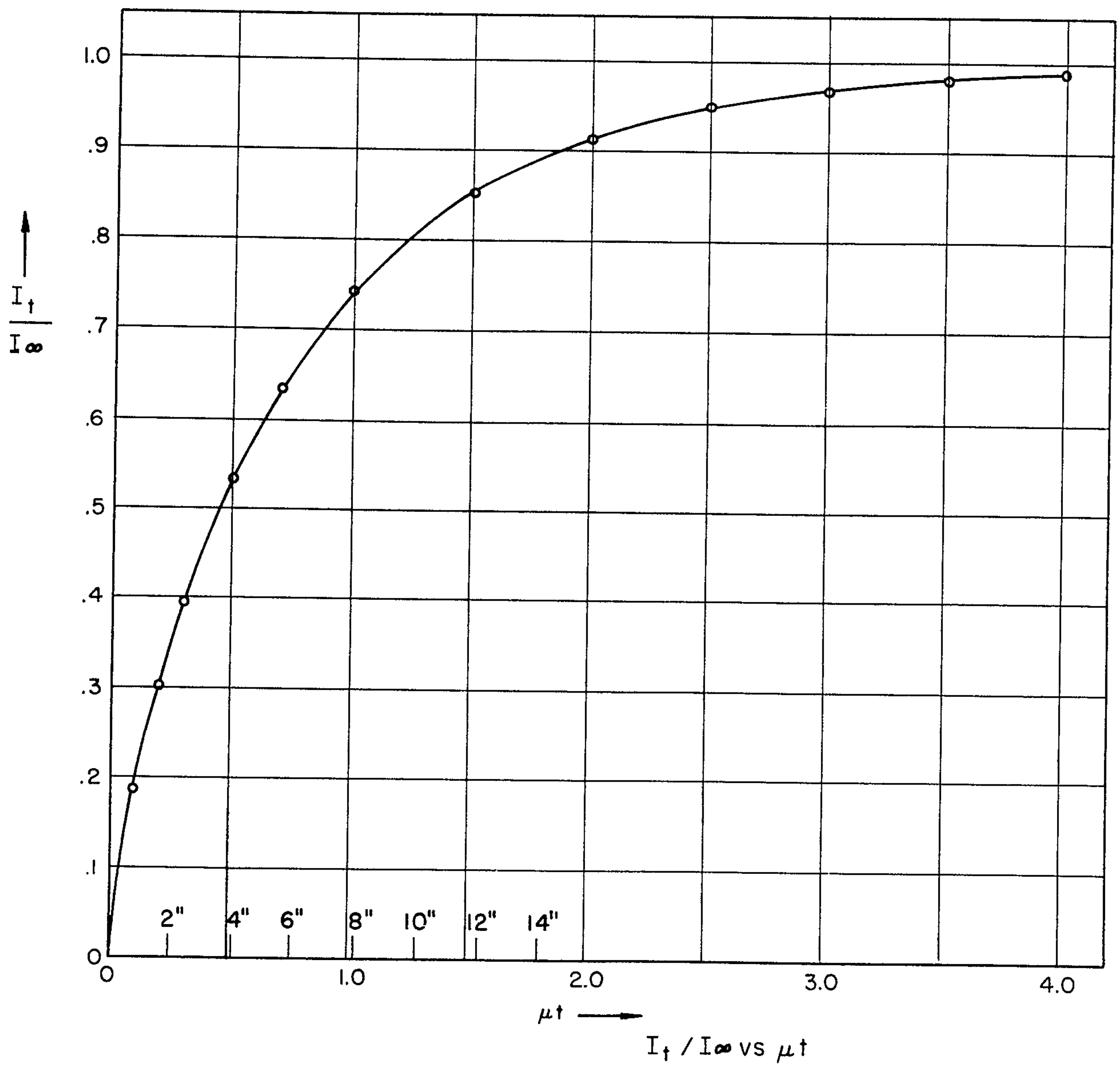

Fig. 17. Flounder Calibration.

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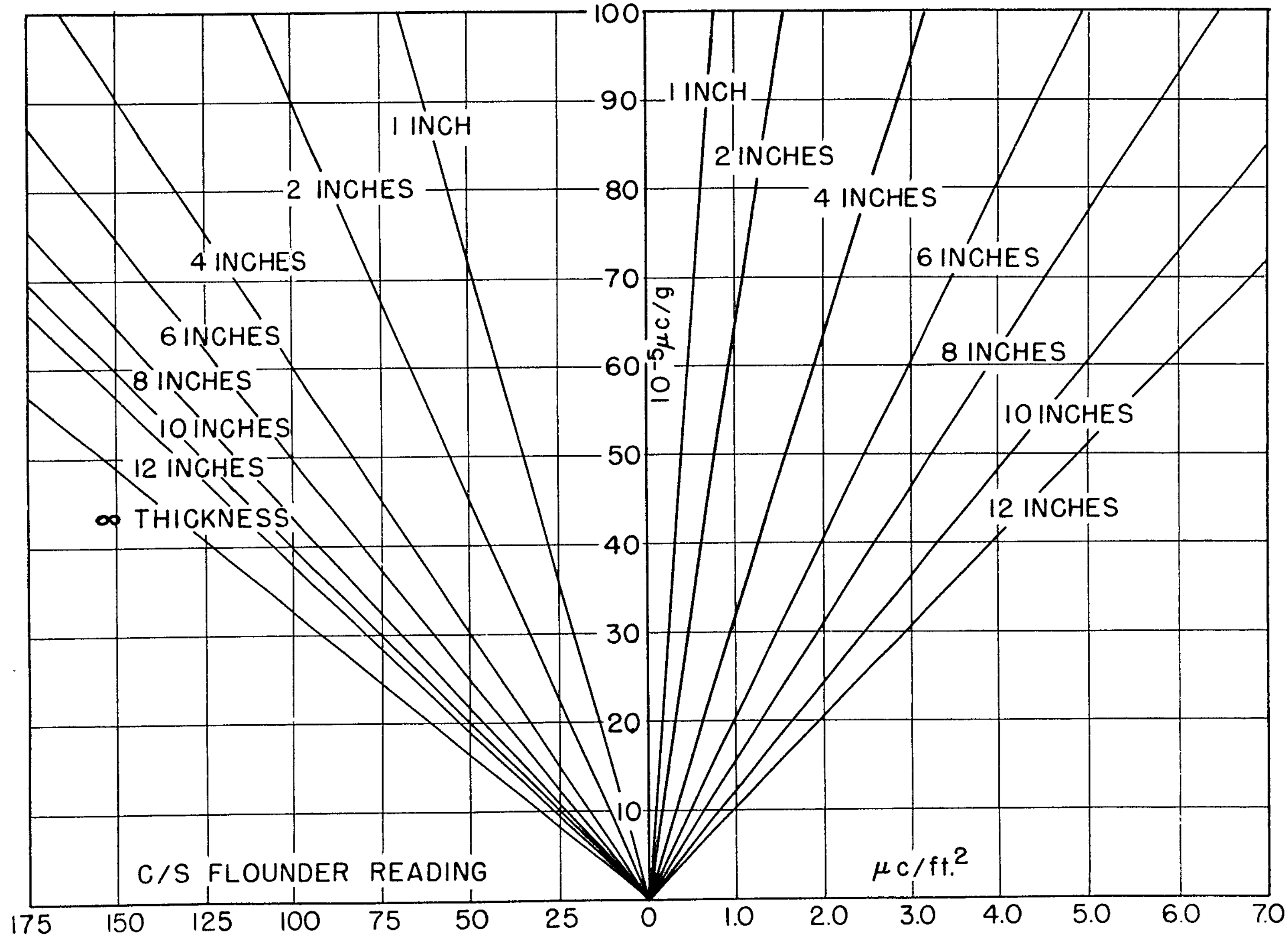

Fig. 18. Flounder Calibration. Gamma Count vs Radioactive Content of Mud.

VI. DISCUSSION

Gamma Count Rate

The gamma count rate shows a gradual increase from the point of entry of the wastes into the Clinch River (CRM 20.8) downstream, peaking at mile 11.0 during 1954 and 1955 and at mile 8.0 during 1956, 1957 and 1958. Downstream from this point the gamma count remains relatively constant except for the low counts obtained at CRM 2.6 and CRM 4.7. At these two points, the silt seems to have been scoured from the river bottom, thereby resulting in low counts.

This increase in radiation level downstream from the point of entry of the wastes is probably due to the fact that during the fall and winter months considerable current is encountered in the Clinch River at the point of entry. The velocity of the water prevents the silt from settling at this point and carries it downstream to be deposited as the water slows down. This phenomenon was encountered repeatedly during the surveys. Any restriction in the river channel caused an increase in velocity and, consequently, a scouring of the sediments and a decrease in gamma count rate. Immediately below the dams, the scouring action extends for a distance of at least 20 miles downstream.

The level of activity dropped off markedly upon entering the Tennessee River and continued to decrease downstream. This is to be expected due to the dilution of the waters of the Clinch by the Tennessee and the subsequent deposition of the silt over a much larger area than in the Clinch. This may be seen from Figure 4 and Figure 5 which show the average gamma count rate versus river mile for the Clinch and Tennessee Rivers. The decrease in activity due to decay is negligible since the time required for the water to travel to the Tennessee is small compared to the half-lives of the radionuclides measured.

The distribution of activity along a traverse was, in general, proportional to the depth of the water. This was especially true in the reservoirs and in the lower reaches of the Clinch River where most of the activity was found in the main channel. Farther up the Clinch, the picture was somewhat complicated by the numerous sharp bends in the river course, and by the current in the river. Here the location of the activity varied depending on whether the traverse was taken on a straight stretch or on a bend in the river and whether the stream bed was uniformly deep or deep on one side and shallow on the other. A more detailed picture of activity distribution may be gained by an examination of the bottom contours and activity profiles of the Clinch and Tennessee Rivers from the 1954 survey shown in Figures 10 through 14. These profiles from the 1954 survey are typical of all the surveys.

The levels of activity in both the Clinch and Tennessee Rivers have shown considerable increase from 1954 to 1958. Of particular note is the increase in gamma count rate on the silt at TRM 475.1, a few miles above the city of Chattanooga. The count rate here increased from a near background count of 8 c/s in 1954 to 20 c/s in 1956. It dropped slightly in 1957 and increased again in 1958 to a level comparable to that of 1956.

The 1957 and 1958 surveys extended downstream from Chattanooga through the next two downstream reservoirs, Hales Bar and Guntersville. The last previous survey of these two reservoirs was done in 1952 by Garner. The gamma count in Hales Bar has increased from 10 c/s in 1952 to 15 c/s in 1957 and 17 c/s in 1958. Guntersville, likewise, showed increases from 1952 to 1958, the readings going from 9 c/s in 1952 to 12 c/s in 1957 and 15 c/s in 1958. How far downstream these increases extend is not known as the only survey to extend beyond Guntersville Reservoir was the 1952 survey which extended to the mouth of the Tennessee River. The increased count in Hales Bar is felt to have its origin in artificial radioactivity introduced upstream. This is based on the fact that there are no major outcroppings of uranium bearing shale upstream from this reservoir and on the fact that the radionuclide cesium was found in the silt to the extent of 4.5 times that found in background silt from Loudoun Reservoir. The increases in Guntersville Reservoir, likewise appear to be the result of artificial radioactivity moving downstream. There is considerable outcropping of uranium bearing shale on the watershed of Guntersville Reservoir and this might result in an increased gamma count in 1958 but would not result in an increase in the cesium content of the silt. The silt showed a cesium content two and one-half times that of background silt from Fort Loudoun Reservoir.

The overall increase in gamma count rate with time may best be seen from reference to Figure 6. Here the average count rates for both the Clinch and Tennessee Rivers are plotted by years for the period 1951 to 1958. In the same figure are given the curies discharged to the Clinch River by years for the corresponding periods of the surveys. It may be noted that, while there are fluctuations in levels of activity, the general trend is up.

The huge increase shown from 1955 to 1956 was due, in large part, to the draining of White Oak Lake with the attendant scouring of contaminated silt from the bottom. A similar increase was shown from 1951 to 1952 except in this case the increase was attributed[1], at least in part, to large releases of relatively short lived material just prior to the 1952 survey. By 1953, in the Clinch River, this material had decayed to a point where the gamma count was considerably less than that in 1952. This was to be expected due to the short half-life of the material in question. However, the activity scoured from the White Oak Lake bottom and discharged to the Clinch River during the fall of 1955 was long-lived material and should have shown very little decay before the 1957 survey. The decrease in count shown in 1957 must be attributed, then, to the re-location of the contaminated silt or to the covering and consequent shielding of it by uncontaminated silt.

The readings obtained with the flounder ranged from an average of 4 to 7 c/s at CRM 27.5 to an average of 181 c/s for the cross section taken at CRM 8.0. The readings of 4 to 7 c/s were taken in the upper reaches of the Clinch on rocky bottom and are lower than the "mud background" of uncontaminated streams in this area. In terms of the radium calibration of the flounder, 181 c/s corresponds to 0.11 mr/hr and 312 c/s, the maximum reading observed, corresponds to 0.20 mr/hr. Based on the maximum permissible occupational exposure to the total body or gonads of 0.1 rem/wk[3], a body in continuous contact with the bottom mud, at the point of maximum reading, would receive 0.034 r/wk or 34% of the maximum permissible occupational exposure. However, maximum permissible exposure to individuals in the neighborhood of the controlled areas should be one-tenth of that for occupational exposure.[2] Based on this figure, 0.01 rem/wk, a body in continuous contact with the mud would receive more than three times the maximum permissible dose. To receive this dose, a body would have to recline on the bottom sediment 24 hours per day, seven days per week. Since this is impossible for any extended period of time, there is very little likelihood of a human receiving this dose. A fisherman sitting on the bank at low lake level, or a person engaged in dredging and handling silt or sand from the river bottom might be presumed to be exposed to this field of radiation for short periods of time.

A person handling sand in a normal 40 hour week would probably receive one-third the dose rate of a person lying on the bottom sediment or 26% of the MPD (0.01 rem/wk).

Gross Beta Activity

Aliquots of the composite silt samples prepared for each cross section were assayed for gross beta activity and were reported in terms of Tl^{204}. While this data does not give an accurate picture of the quantity of activity present, it is useful for comparative purposes. This data is presented in Figures 7 and 8 in units of 10^{-5} μc per gram of dried silt vs river mile.

Beta-Gamma Ratio

In an effort to relate flounder readings to radioactive content of the bottom mud, samples of the composites from the 1954 survey were counted for both beta and gamma. If this ratio was constant, a fairly reliable value for the amount of radioactivity in the mud could be obtained from the gamma measurements made with the flounder. This ratio, however, was not constant, as is shown by Figure 18, which is a plot of beta-gamma ratio vs river mile for both the Clinch and Tennessee Rivers. An inspection of these graphs shows the beta-gamma ratio to be less erratic in the Tennessee than in the Clinch River. The range of both, however, appears to be approximately a factor of 2. The variation in the beta-gamma ratio from one cross section to another is probably due to different compositions of radioactive wastes in the mud. This could be due, in part, to selective adsorption of isotopes on different types of soils.

The average gross beta values for the Clinch and Tennessee Rivers are compared to the average gamma counts obtained with the flounder in Table VII. The beta-gamma ratio was not constant for the Clinch

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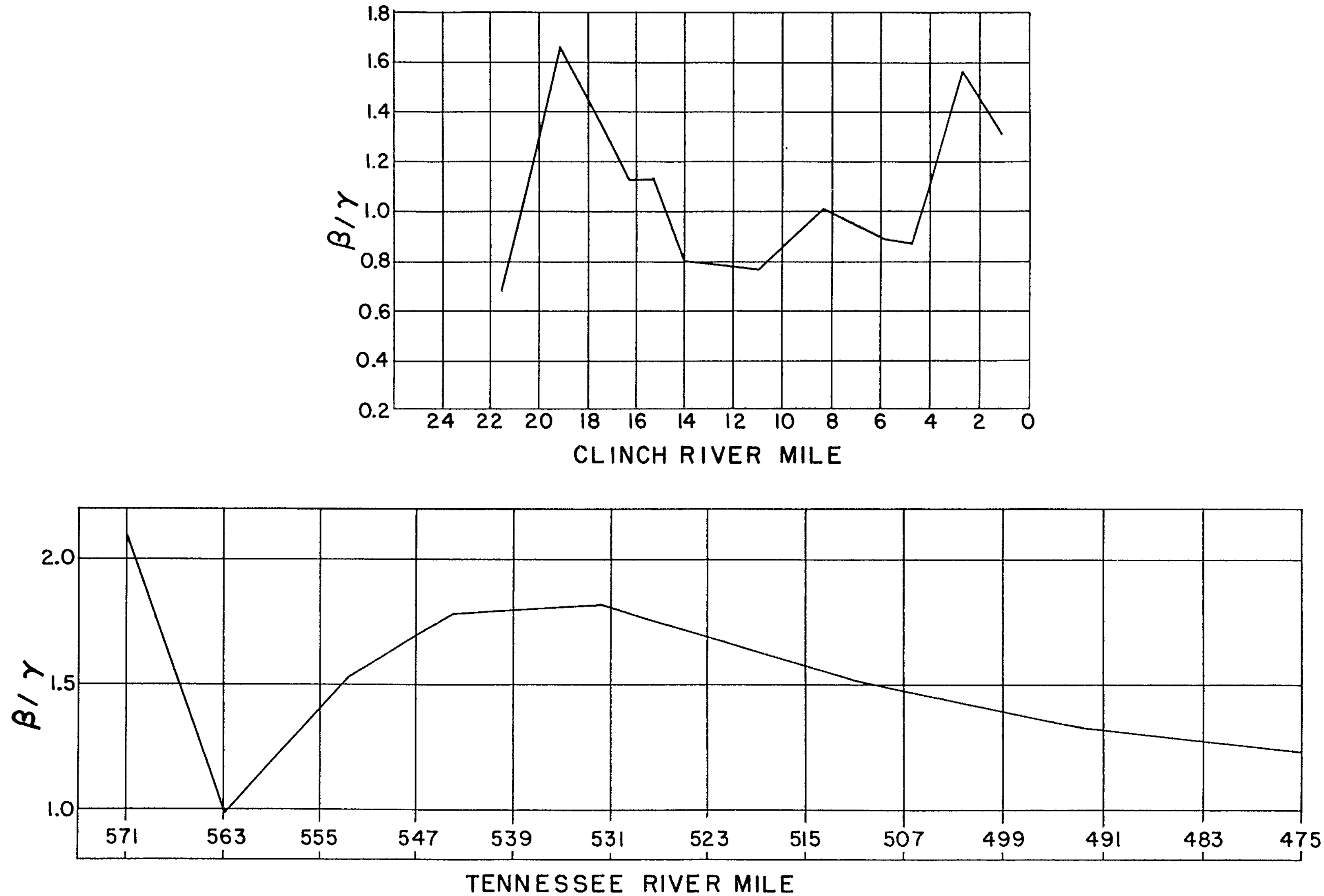

Fig. 19. Beta-Gamma Ratio.

but varied only about 13% in the Tennessee through 1957. It dropped considerably in 1958.

Identification of Activity

Radiochemical analyses were run on the composite silt samples. The samples were assayed for cesium, strontium, cerium, tri-valent rare earths, ruthenium, niobium, zirconium, and cobalt. These results, except niobium and zirconium, are given in Tables I through VI. The niobium and zirconium content of the silt was very low and for the sake of brevity are not included here.

Silt from Fort Loudoun Reservoir, presumably containing no fission products from ORNL, was analyzed for the same elements as was the river silt and should represent background levels of activity due to Laboratory contamination, etc.

The major radioactive constituents of the Clinch and Tennessee River silt are cesium, cerium, and cobalt with smaller amounts of strontium, yttrium, tri-valent rare earths, and ruthenium present. The concentration of most of the radionuclides have increased from 1954 to 1956 with the greatest increases being shown by cesium, cerium, and cobalt. The concentration of all radionuclides, with the exception of cesium, showed a decrease in 1957. The 1958 data show a decrease in the cesium and cobalt content of the silt while the remaining nuclides show an increase from 1957.

The average concentration of each radionuclide in the silt of the

Clinch and Tessessee Rivers for the years 1954 through 1958 is shown in Figure 9. The total number of curies of each radionuclide discharged to the Clinch River for corresponding periods is presented for comparison. The best correlation of radionuclide discharged to radionuclide concentration found is shown by cesium. This is not too surprising when it is noted that cesium is readily removed from water by adsorption on soil particles. The very large increase in the amount of cesium discharged in 1956 is probably due to the draining of White Oak Lake during the fall of 1955. During and following this operation, considerable silt from the lake bottom was discharged to the Clinch River. This silt was highly contaminated with radioactive cesium.

VII. CONCLUSION

On the basis of the data observed to date, a body in continuous contact with the bottom sediment would receive 3 times the MPD[2] for non-occupational exposure in the neighborhood of a controlled areas. Since it is unlikely that a person would be in continuous contact with the bottom sediment for any extended period of time, a more practical approach might be to consider a fisherman sitting on the bank at low lake level, or a man engaged in dredging and handling sand or silt from the lake bottom. A person engaged in such an operation so that he would receive one-third as much radiation in a 40 hour week as if he were reclining on the bottom, would receive only 26% of MPD for such non-occupational exposure.

If the case of the fisherman sitting on the bank of the Clinch River at low lake level is considered, it is felt that the above figures would still apply. While the MPD to the gonads[3] is the same as that to the total body, the gonads, in this case might be exposed to three times the field of radiation as the total body of the worker. and hence, would receive the same total dose in one-third the time. This would allow the fisherman to spend 13 hrs/week fishing on the bank. This is not an altogether unreasonable length of time.

If conditions were created such that exposures greater than the MPD were possible then the river system would have reached maximum capacity, and any additional wastes would present special problems.

Since most of the silt would be removed from the water by water treatment plants and since the concentration of radioactivity in solution on the average does not exceed the MPC for continuous use, it is believed that no ingestion hazard exists due to the discharge of the present amount of radioactive wastes to the Clinch River. This will be discussed in a subsequent report.

It is concluded that no immediate hazard exists due to the reconcentration of radioactive materials in downstream bottom sediments. However, if the amount of radioactivity in the bottom sediment continues to increase for the next few years, it will be necessary to re-evaluate our present waste disposal policy in order to further restrict the release of radioactive wastes to the Clinch River.

The most probable effect of the radioactive sediment on industry would be an increased background counting rate if sand from the river bottom were used in making concrete for the construction of counting rooms of instrument laboratories. The problem of the radioactivity in solution in the river water would have to be considered before using the downstream water as process water in the manufacture of film emulsions or other photographic materials.

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